

FLUID RESISTANT SILICONE ENCAPSULANT

FIELD OF THE INVENTION

The present invention relates to a fluid resistant silicone encapsulant in the form of a cross-linked and cross-linkable organosilicon polymer.

BACKGROUND OF THE INVENTION

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It is known in the art to prepare cross-linked and cross-linkable silicone elastomers which are mainly comprised of two types of liquid polysiloxanes; one having vinyl (or general $C=C$) attached to the main chain and the other having hydrogen directly attached to silicone atoms. The addition curing (or crosslinking) reaction to form elastomeric materials occurs through hydrosilation in the presence of platinum or other metal-containing catalysts under room temperature or heating conditions. The substitution groups attached to the silicone chain can be methyl, phenyl, or fluoroalkyl (mostly trifluoropropyl). The fluoroalkyl substituted silicone (fluorosilicone) generally displays good chemical resistance and is commonly used as coating, potting or encapsulation material to protect electric/electronic components and assemblies.

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The preparation of curable organosilicon prepolymers or cross-linked thermosetting polymers through a hydrosilation reaction of polycyclic polyene (providing an active C=C) and reactive cyclic polysiloxane or tetrahedral siloxysilane (providing SiH) in the presence of platinum-containing catalysts
5 under heating is also known in the art. The resulting fully cross-linked materials display high rigidity and brittleness, a relatively high T_g , very high temperature resistance, water insensitivity and oxidation resistance. Examples of these types of polymers are found in U.S. Patent Numbers 4,902,731 and 4,877,820.

10 Attempts have been made to reduce the brittleness and rigidity and increase the toughness of such polymers. U.S. Patent No. 5,171,817 discloses such an organosilicone polymer in which reactive siloxane elastomers having carbon-carbon double bonds are added to the composition to form discontinuous phases in the rigid continuous polymer matrix after
15 curing. For example, unsaturated diphenyl dimethyl siloxane elastomers are utilized to increase toughness and adhesion without reducing any of the other properties of the polymer. U.S. Patent No. 5,196,498 discloses the use of a second silicone as a modifier to reduce the viscosity and brittleness of the crosslinked polymers. The second silicone compound, which has reactive
20 hydrocarbyl group, is a cyclic siloxane and most preferably tetravinyltetramethyl cyclotetrasiloxane or pentavinylpentamethyl cyclopentasiloxane.

Accordingly, it would be advantageous for a polymer to have certain properties of known polymers without the brittleness and high rigidity that are
25 usually associated therewith. It would be further advantageous for the

polymer to have high acid and fuel resistance such that it would be suitable for use in fields which require polymers having more flexibility.

One potential use of such polymers is in the automotive industry as an encapsulant for items such as sensors, and especially as an encapsulant for pressure sensors. Such encapsulants must have an extremely high resistance to acids and fuels. For example, two fuels commonly utilized for material evaluation by the automobile industry, Fuel C and Fuel CM85, both cause polymer degradation to many known polymers. Fuel C is a hydrocarbon fuel which is approximately 50% by volume isooctane and 50% by volume toluene. Fuel CM85 comprises Fuel C containing 85% by volume methanol. In addition many materials are tested by the automotive industry for their resistance to used synthetic oil, which also causes polymer degradation. For the purpose of this patent, this is defined as Mobile 1 Oil, which has been used to lubricate an automotive engine for a minimum of 3,000 miles.

TM IS
MOBIL 1

SUMMARY OF THE INVENTION

The present invention discloses a cross-linkable and cross-linked organosilicon polymer which is prepared from a mixture of a reactive polysiloxane resin having both reactive carbon-carbon double bonds and silicone-hydrogen groups, characterized by alternating structures of polycyclic polyene residue and cyclic polysiloxane (or tetrahedral siloxysilane) residue, hereafter referred to as a silicon hydrocarbon crosslinking agent, and either a vinyl terminated fluorine-containing polysiloxane or a vinyl terminated phenyl-substituted polysiloxane. In an

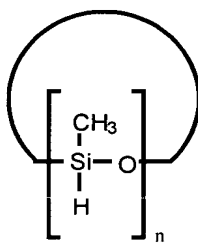
alternative embodiment, the polymer comprises a mixture of vinyl terminated phenyl-substituted polysiloxane and vinyl terminated fluorine containing polysiloxane and the silicon hydrocarbon crosslinking agent.

5 DETAILED DESCRIPTION OF THE INVENTION

Upon exposure to harsh environments, such as those associated with fuels and/or acids and/or extreme temperatures, fluorosilicone and phenyl silicone polymers can breakdown and degrade. Consequently, elastomers comprising either material only provide moderate resistance to degradation upon exposure to fuels and/or acids and/or extreme temperatures. A combination of phenyl-silicone and/or fluorosilicone with certain forms of cross-linking agents has been found to result in a polymer which maintains its elastomeric properties during and after exposure to fuels and acids. Specifically, a vinyl terminated fluorine-containing polysiloxane and/or a vinyl terminated phenyl-substituted polysiloxane have been shown to be effective when combined with silicon hydrocarbon crosslinking agents. Exemplary vinyl terminated fluorine-containing polysiloxanes include Nusil PLY-7801, Nusil PLY (1-5)-7580, supplied by Nusil Technology, 1050 Cindy Lane, Carpinteria, CA 93013 and Gelest FMV-4031, supplied by Gelest, Inc., Tullytown, PA 19007-6308, USA. Exemplary vinyl terminated phenyl-substituted siloxanes include Nusil PLY (1-5)-7560, Nusil PLY-7664, Nusil PLY-7450, supplied by Nusil Technology; Gelest PMV-9925, Gelest PDV-0325, Gelest PDV-0331, Gelest PDV-0341, Gelest PDV-0346, Gelest PDV – 0525, Gelest PDV-0541, Gelest PDV-1625, Gelest PDV –1631, Gelest PDV

1635, Gelest PDV-1641, Gelest PDV-2331, Gelest PDV-2335, supplied by Gelest, Inc; Andersil SF 1421; Andersil SF 1712; supplied by Anderson & Associates LLC., Summit, NJ. The reaction of many standard cross-linking agents, such as linear hydrosiloxane chain crosslinkers with either dimethyl or 3,3,3-trifluoropropyl substitution, with the polysiloxanes described above results in polymers with little or only moderate fuel and acid resistance. It has been determined that combining vinyl-terminated phenyl-substituted polysiloxane or vinyl terminated fluorine-containing polysiloxane with a silicon hydrocarbon crosslinking agent, provides a polymer with superior resistance to the harsh conditions imposed by fuels and acids.

Exemplary silicon hydrocarbon crosslinking agents are comprised of a cyclic or linear poly(organohydrosiloxane) having at least 30% of its silicon-hydrogen groups reacted with hydrocarbon residues derived from polycyclic polyenes. Numerous examples of poly(organohydrosiloxane) are known. One exemplary poly(organohydrosiloxane) is methylhydrocyclosiloxane, examples of typical structures include



with typically D4 (n=4) and D5 (n=5). Further exemplary poly(organohydrosiloxanes) include Tetra- and penta-methylcyclotetrasiloxane; tetra, penta, hexa and hepta-methylcyclopentasiloxane; tetra-, penta- and hexa-methylcyclohexasiloxane;

tetraethyl cyclotetrasiloxanes and tetraphenyl cyclotetrasiloxane; or blends thereof. Exemplary linear siloxanes include tetrakisdimethylsiloxysilane, tetrakisdiphenylsiloxysilane, and tetrakisdialkylsiloxysilane.

The silicon hydrocarbon crosslinking agents used in this invention are formed by the hydrosilation reaction of the poly(organohydrosiloxane) with a polycyclic polyene. The stoichiometric ratio of carbon-carbon double bonds to silicon-hydrogen linkages can be in the range of about 2:1 to 1:4. A preferred range is about 1:1. Useful cyclic polyenes are polycyclic hydrocarbon compounds having at least two non-aromatic, non-conjugated carbon-to-carbon double bonds. Exemplary compounds are well known in the art, and include cyclopentadiene oligomers such as dicyclopentadiene,

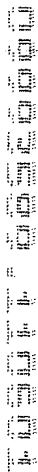
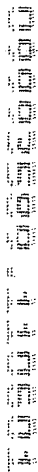


and tricyclopentadiene,



Further exemplary compounds include the Diels-Alder oligomers of the dicyclopentadiene and tricyclopentadiene species described above and substituted derivatives of the dicyclopentadiene and tricyclopentadiene species described above including dimethanohexahydronaphthalene, methyl dicyclopentadiene; and any mixture of these compounds.

An exemplary silicon hydrocarbon crosslinking agent has the following structure

[illegible]

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2
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In another preferred formulation, the resulting polymer comprises about 1 to 40 wt% and most preferably 1-20 wt% of a vinyl terminated fluorine containing polysiloxane, which is about 20 to 90 mol% and most preferably about 20-60 mol% substituted with 3,3,3-trifluoropropyl groups, and about 60 to 99 wt% and most preferably about 80 to 99 wt% of the silicon hydrocarbon crosslinking agent described above. The resulting polymer is a cross-linked, rigid silicone which demonstrates reduced brittleness and improved toughness compared to the fully cross linked silicon hydrocarbon material. Furthermore the resulting polymer demonstrates increased hydrophobicity and lippophobicity indicating that this material will also exhibit resistance to fuels, oils and acids. This type of material is useful for the protective encapsulation of electric/electronic components where strength, toughness and mechanical stability are required.

In another preferred formulation, the resulting polymer comprises about 20 to 99 wt% and most preferably about 60 to 99 wt% of a vinyl terminated phenyl-substituted siloxane, which is about 1 to 40 mol% and most preferably about 2 to 20 mol% phenyl substituted, and about 1 to 80 wt% and most preferably about 1 to 40 wt% of the silicon hydrocarbon crosslinking agent described above. The resulting polymers are a range of cross-linked silicones which vary in hardness from soft gels to elastomers and rigid materials. The gel materials demonstrate superior strength and toughness while retaining the flexibility normally associated with this type of material. The rigid materials demonstrate a degree of flexibility and resilience beyond that expected of typical rigid elastomers. Both categories of material have been shown to be resistant to acid and alcohol based fuels. Materials of

this type are useful as coating, potting or encapsulant materials to protect electric/electronic components and assemblies.

In another preferred formulation, the resulting polymer comprises about 64 to 99 wt% and most preferably about 77 to 90 wt% of a blend of a vinyl terminated fluorine-containing polysiloxane and a vinyl terminated phenyl-substituted polysiloxane and about 1 to 36 wt% and most preferably about 10 to 23 wt% of the silicon hydrocarbon crosslinking agent described above. The blend of vinyl terminated fluorine-containing polysiloxane and a vinyl terminated phenyl-substituted polysiloxane comprises about 70 to 99 wt% and most preferably about 80 to 99 wt% of a vinyl terminated fluorine-containing polysiloxane, which is about 20 to 90 mol% and most preferably about 20 to 60 mol% substituted with 3,3,3-trifluoropropyl groups, and about 1 to 30 wt% and most preferably 1 to 20 wt% of a vinyl terminated phenyl-substituted siloxane, which is 1 to 40 mol% and most preferably about 2 to 20 mol% phenyl substituted. The resulting polymers are flexible cross-linked gels. The polymers would be expected to demonstrate similar levels of fuel, oil and acid resistance seen from the fluorosilicone in combination with the silicon hydrocarbon cross linker and the phenylsilicone in combination with the silicon hydrocarbon cross linker. Such polymers would also be expected to be useful as encapsulants, coatings and sealants for the automotive, avionics and general electronics markets.

The vinyl terminated fluorine-containing polysiloxane and/or the vinyl terminated phenyl-substituted polysiloxane and the silicon hydrocarbon crosslinking agents are combined via an addition-cure reaction. The vinyl terminated fluorine-containing polysiloxane is blended with a group VIII metal

EXAMPLES

The invention can be illustrated by the following examples.

Examples 1 to 3 include gels prepared from a vinyl terminated
5 fluorine containing polysiloxane and the silicon hydrocarbon cross linking
agent.

Example 1

An encapsulant polymer gel was prepared from a vinyl terminated
10 fluorine containing polysiloxane which is 50 mol% substituted with 3,3,3-
trifluoropropyl groups and the silicon hydrocarbon cross linking agent
described above, via a two-part process. To prepare the first part, a mixing
vessel equipped with a low shear stirrer was charged with 50 wt% of
compound A, which is the vinyl terminated polysiloxane, given in Table 1.
15 With low speed stirring, compound B, which is the group VIII metal catalyst
and other additives, given in Table 1 were added to the mixing vessel and
blended for a period of 5-30 minutes at room temperature. Entrapped air was
removed from the resulting blend by evacuating the mixture in a vacuum
chamber capable of providing a vacuum of 29 mmHg. To prepare the second
20 part, a further mixing vessel equipped with a low shear stirrer was charged
with the remaining 50 wt% of compound A, which is the vinyl terminated
polysiloxane, given in Table 1. With low speed stirring, compound C, which is
the cross linking agent, was added to the reaction vessel and blended for a
period of 5 to 30 minutes at room temperature. Entrapped air was removed
25 from the resulting blend by evacuating the mixture in a vacuum chamber

capable of providing a vacuum of 29 mmHg. The two parts thus prepared were mixed. The reaction mixture containing compounds A and B was added to the reaction mixture containing compounds A and C and mixed for 5 to 30 minutes at room temperature. Entrapped air was removed from the resulting blend by evacuating the mixture in a vacuum chamber capable of providing a vacuum of 29 mmHg. The resulting blend was poured into molds suitable for making test pieces and cured at 150°C for 1 hour.

Table 1

Compound	Material	Amount
A	Nusil PLY-7801 (%)	85.8
B	Baysilone U Catalyst PT/L (%)	0.3
	A-187 (%)	1.0
C	SC-1 (%)	12.9

Baysilone U Catalyst PT/L is a group VIII catalyst supplied by GE Silicones, 260 Hudson River Road, Waterford, NY 12188. A187 is a silane adhesion promoter supplied by OSi Specialties Inc., PO Box 38002, South Charleston, West Virginia, 25303.

Specimens were cut from each cured piece and measured for physical properties according to ASTM D2240 and ASTM D 412 (using Die D to cut the pieces and a tensile rate of 20inch/minute) and adhesion properties according to ASTM D-413-82 (type B 90°, peel rate 0.2 inches per minute) with the results shown below.

Hardness (Shore 00)	40
Tensile Strength (psi)	56
Elongation (%)	420
Adhesion to PPS (J/m ²)	149
Adhesion to Gold (J/m ²)	175

Note: In general values associated with hardness, tensile strength, % elongation, toughness and adhesion are subject to approximately a 10% experimental error.

- 5 Specimens were also examined for heat resistance according to ASTM D 573 and chemical resistance according to ASTM D 471, part 15.4.1 (using Die D). The results are shown in Tables 2 to 5.

Table 2: Heat at 180°C

Time (hours)	Initial	200	400
Hardness (Shore 00)	40	62	69
Weight change (%)	-	-0.5%	-1.66

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Table 3: Fuel C and Fuel CM 85 for 200 hours at 25°C

	Fuel C	Fuel CM 85
Tensile strength retention (%)	164	126
Elongation retention (%)	146	125
Adhesion to PPS retention (%)	159	146
Adhesion to gold retention (%)	150	120

Table 4: Mobil 1 Oil at 140°C

Time (hours)	200	400	600
Tensile strength retention (%)	112	90	110
Elongation retention (%)	121	102	102
Adhesion to PPS retention (%)	85	82	83
Weight gain (%)	+2.3	+2.7	-

Table 5: Nitric and sulfuric acid at pH 1.6 and 85°C

Time (hours)	Nitric acid		Sulfuric acid	
	620	1000	620	1000
Tensile strength retention (%)	104	121	122	100
Elongation retention (%)	83	95	92	80
Adhesion to PPS retention (%)	100	84	106	106
Adhesion to gold retention (%)	88	80	73	87

The performance properties detailed above describing Example 1 illustrate that this vinyl terminated fluorine containing polysiloxane in

- 5 combination with the silicon hydrocarbon crosslinker is a soft gel material with excellent strength, flexibility and adhesion properties. Moreover, excellent retention of these properties is observed on exposure of this material to fuels, oils and acids.

Example 2

- 10 Example 2 represents four formulations which demonstrate that similar properties to the material described in Example 1 can be achieved for a range of levels of the silicon hydrocarbon crosslinker. Encapsulant polymer gels were prepared from varying ratios of a vinyl terminated fluorine containing polysiloxane which is 50 mol% substituted with 3,3,3-
- 15 trifluoropropyl groups and the silicon hydrocarbon cross linking agent described above. Materials in Example 2 were formulated according to the method described in Example 1, via a two part process. Compound B shown in Table 6 was blended with 50 wt% of compound A. Compound C shown in Table 6 was blended with the remaining 50 wt% of compound A. The two
- 20 parts were mixed, de-aerated, poured into molds suitable for making test pieces and cured at 150°C for 1 hour.

Table 6

Compound	Material	Ex 2.1	Ex 2.2	Ex 2.3	Ex 2.4
A	Nusil PLY-7801 (%)	93.70	86.67	81.70	75.70
B	PT-L (%)	0.30	0.30	0.30	0.30
C	SC-1 (%)	6.00	13.03	18.00	24.00

Specimens were cut from each cured piece and measured for physical properties according to ASTM D2240 and ASTM D 412 (using Die D

- 5 to cut the pieces and a tensile rate of 20inch/minute) with the results shown below.

	Ex 2.1	Ex 2.2	Ex 2.3	Ex 2.4
Hardness (Shore 00)	56	59	63	65
Tensile strength (psi)	45.39	77.79	106.4	70.68
Elongation (%)	210.7	218.8	194.9	139.5
Toughness (in.lbs/in ³)	41.07	66.09	85.43	47.44

Specimens were also examined for heat resistance according to ASTM D 573 and chemical resistance according to ASTM D 471, part 15.4.2,
10 (using Die D). The results are shown in Tables 7 to 10.

Table 7: Heat for 200 hours at 180°C

	Ex 2.1	Ex 2.2	Ex 2.3	Ex 2.4
Hardness (Shore 00)	69	69.5	72	74
Tensile strength retention (%)	152	137	110	106
Elongation retention (%)	58	58	54	44
Toughness retention (%)	94	77	63	42

Table 8: Fuel C for 200 hours at 25°C

	Ex 2.1	Ex 2.2	Ex 2.3	Ex 2.4
Hardness (Shore 00)	57	59	63.5	65
Tensile strength retention (%)	134	120	122	114
Elongation retention (%)	107	105	104	106
Toughness retention (%)	178	145	133	118

Table 9: Fuel CM 85 for 200 hours at 25°C

	Ex 2.1	Ex 2.2	Ex 2.3	Ex 2.4
Hardness (Shore 00)	56.5	59	63	65
Tensile strength retention (%)	117	94	118	120
Elongation retention (%)	107	96	106	108
Toughness retention (%)	139	100	125	123

Table 10: Nitric acid for 120 hours at pH 1.0, 85°C

	Ex 2.1	Ex 2.2	Ex 2.3	Ex 2.4
Hardness (Shore 00)	-	60	65	64
Tensile strength retention (%)	-	105	111	88
Elongation retention (%)	-	97	99	89
Toughness retention (%)	-	99	104	80

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Example 3

Example 3 represents a further formulation which demonstrates that similar properties to the material described in Example 1 can be achieved for vinyl terminated fluorine containing polysiloxanes with alternative levels of 3,3,3-trifluoropropyl substitution. An encapsulant polymer gel was prepared from a vinyl terminated fluorine containing polysiloxane which is 40 mol% substituted with 3,3,3-trifluoropropyl groups and the silicon hydrocarbon cross linking agent described above. The material in Example 3 was formulated according to the method described in Example 1, via a two part process. Compound B shown in Table 11 was blended with 50 wt% of compound A. Compound C shown in Table 11 was blended with the remaining 50 wt% of compound A. The two parts were mixed, de-aerated, poured into molds suitable for making test pieces and cured at 150°C for 1 hour.

Table 11

Compound	Material	
A	FMV-4031 (%)	81.70
B	PT-L (%)	0.30
C	SC-1 (%)	18.00

- Specimens were cut from each cured piece and measured for physical properties according to ASTM D2240 and ASTM D 412 (using Die D to cut the pieces and a tensile rate of 20 inch/minute) with the results shown below.

Hardness (Shore 00)	60
Tensile strength (psi)	89
Elongation (%)	268
Toughness (in.lbs/in ³)	104

Specimens were also examined for heat resistance according to ASTM D 573 and chemical resistance according to ASTM D 471, part 15.4.2, (using Die D). The results are shown in Table 12.

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Table 12: Heat and chemical resistance

Conditions Time (hours)	Heat 180°C 200	Fuel C 25°C 200	Fuel CM 85 25°C 200	Nitric acid pH 1.0, 85°C 120
Hardness (Shore 00)	67	62	61	63
Tensile strength retention (%)	139	91	93	119
Elongation retention (%)	53	93	97	97
Toughness retention (%)	67	94	94	107

Comparative Example 1

- A further encapsulant polymer gel was prepared from a vinyl terminated fluorine containing polysiloxane which is 50 mol% substituted with 3,3,3-trifluoropropyl groups and a cross linking agent that is a linear hydrosiloxane with dimethyl substitution, Masil XL-1, supplied by PPG

Industries Inc., Specialty Chemicals, 3938 Porett Drive, Gurnee, IL 60031. A further encapsulant polymer gel was prepared from a vinyl terminated fluorine containing polysiloxane which is 50 mol% substituted with 3,3,3-trifluoropropyl groups and a cross linking agent that is a linear hydrosiloxane with 3,3,3-trifluoropropyl substitution, SMP 9951-22, supplied by Nusil Technology, 1050 Cindy Lane, Carpinteria, CA 93013. Materials in Comparative Example 1 were formulated according to the method described in Example 1, via a two part process. Compound B shown in Table 13 was blended with 50 wt% of compound A. Compound C shown in Table 13 was blended with the remaining 50 wt% of compound A. The two parts were mixed, de-aerated, poured into molds suitable for making test pieces and cured at 150°C for 1 hour.

Table 13

Compound	Material	CEx 1.1	CEx 1.2
A	Nusil PLY-7801 (%)	81.70	81.70
B	PT-L (%)	0.30	0.30
C	Masil XL-1 (%)	18.00	-
	SMP 9951-22 (%)	-	18.00

- 15 Specimens were cut from each cured piece and measured for physical properties according to ASTM D2240 and ASTM D 412 (using Die D to cut the pieces and a tensile rate of 20inch/minute) with the results shown below.

	CEx 1.1	CEx 1.2
Hardness (Shore 00)	59	46
Tensile strength (psi)	38	35
Elongation (%)	117	236
Toughness (in.lbs/in ³)	39	49

Specimens were also examined for heat resistance according to ASTM D 573 and chemical resistance according to ASTM D 471, part 15.4.2, (using Die D). The results are shown in Tables 14 to 17.

Table 14: Heat for 200 hours at 180°C

	CEx 1.1	CEx 1.2
Hardness (Shore 00)	73	54
Tensile strength retention (%)	108	45
Elongation retention (%)	37	50
Toughness retention (%)	14	6

5

Table 15: Fuel C for 200 hours at 25°C

	CEx 1.1	CEx 1.2
Hardness (Shore 00)	62.5	53
Tensile strength retention (%)	83	64
Elongation retention (%)	87	71
Toughness retention (%)	40	36

Table 16: Fuel CM 85 for 200 hours at 25°C

	CEx 1.1	CEx 1.2
Hardness (Shore 00)	61	45
Tensile strength retention (%)	94	75
Elongation retention (%)	69	86
Toughness retention (%)	44	56

10

Table 17: Nitric acid for 120 hours at pH 1.0, 85°C

	CEx 1.1	CEx 1.2
Hardness (Shore 00)	53	42
Tensile strength retention (%)	28	67
Elongation retention (%)	110	94
Toughness retention (%)	8	44

The performance properties detailed above describing Comparative Example 1 illustrate that this vinyl terminated fluorine containing polysiloxane

in combination with cross linking agents that are linear hydrosiloxanes with either dimethyl or 3,3,3-trifluoropropyl substitution are soft gel materials with inferior strength and toughness compared with Examples 1 to 3. Moreover these properties are observed to deteriorate on exposure of this material to both fuels and acids, indicating polymer degradation.

Example 4

Example 4 describes a range of rigid polymers prepared from a vinyl terminated fluorine containing polysiloxane and the silicon hydrocarbon cross linking agent. These were prepared from varying ratios of a vinyl terminated fluorine containing polysiloxane which is 50 mol% substituted with 3,3,3-trifluoropropyl groups and the silicon hydrocarbon cross linking agent described above. Materials in Example 4 were formulated according to the method described in Example 1, via a two part process. Compound B shown in Table 18 was blended with 50 wt% of compound A. Compound C shown in Table 18 was blended with the remaining 50 wt% of compound A. The two parts were mixed and de-aerated.

Table 18

Compound	Material	Ex 4.1	Ex 4.2	Ex 4.3	Ex 4.4
A	Nusil PLY-7801 (%)	-	4.99	9.97	19.94
B	PT-L (%)	0.30	0.30	0.30	0.30
C	SC-1 (%)	99.70	94.72	89.73	79.76

Films coated on glass slides were prepared by drawing down material using 2 mil tape to define the film thickness. These films were cured at 150°C for 1 hour. Contact angle data for water and toluene on the films were measured by the sessile drop method: a drop of the test fluid was

placed onto the film surface in air and the contact angle was measured after ten seconds at 25°C, with the results shown below.

		Ex 4.1	Ex 4.2	Ex 4.3	Ex 4.4
Hardness	(Shore D)	71	68.3	64.3	62.3
Contact angle:	Water	78°	78°	85°	86°
	Toluene	0°	23°	25°	30°

The performance properties detailed above describing Example 4

- 5 illustrate that the incorporation of this vinyl terminated fluorine containing polysiloxane with the silicon hydrocarbon crosslinker results in a rigid polymer with reduced hardness compared with the fully crosslinked silicon hydrocarbon material, thus the polymer would be expected to have reduced brittleness and improved toughness compared with the fully crosslinked
- 10 silicon hydrocarbon material. Moreover, Example 4 demonstrates that this improved toughness is accompanied by an increase in contact angle for both water and toluene, indicating that the polymer has increased hydrophobicity and lipphobicity, thus the polymer would be expected to have improved resistance to fuels, oils and acids.
- 15 Examples 5 to 7 include elastomers prepared from a vinyl terminated phenyl substituted polysiloxanes and the silicon hydrocarbon cross linking agent.

Example 5

- 20 An encapsulant polymer elastomer was prepared from a vinyl terminated phenyl-substituted polysiloxane which is 6 mol% substituted phenyl groups and the silicon hydrocarbon cross linking agent described above. The material in Example 5 was formulated according to the method

described in Example 1, via a two part process. Compound B shown in Table 19 was blended with 50 wt% of compound A. Compound C shown in Table 19 was blended with the remaining 50 wt% of compound A. The two parts were mixed, de-aerated, poured into molds suitable for making test pieces and cured at 150°C for 1 hour.

Table 19

Compound	Material	
A	Andersil SF 1721 (%)	86.9
B	PT-L (%)	0.1
C	SC-1 (%)	13.0

Specimens were cut from each cured piece and measured for physical properties according to ASTM D2240 and ASTM D 412 (using Die D to cut the pieces and a tensile rate of 20inch/minute) and adhesion properties according to ASTM D-413-82 (type B 90°, peel rate 0.2 inches per minute) with the results shown below.

Hardness (Shore A)	14
Tensile Strength (psi)	130
Elongation (%)	285
Adhesion to PPS (J/m ²)	121
Adhesion to Gold (J/m ²)	86

Specimens were also examined for heat resistance according to ASTM D 573 and chemical resistance according to ASTM D 471, part 15.4.1 (using Die D). The results are shown in Tables 20 to 22.

Table 20: Heat at 180°C

Time (hours)	initial	200
Hardness (Shore A)	14	28
Weight change (%)	-	-1.76

Table 21: Fuel CM 85 for 150-200 hours at 25°C

	Fuel CM 85
Tensile strength retention (%)	78
Elongation retention (%)	94
Adhesion to gold retention (%)	124

Table 22: Sulfuric Acid at pH 1.6, at 85°C

	Sulfuric acid	
Time (hours)	620	1000
Tensile strength retention (%)	69	95
Elongation retention (%)	77	166
Adhesion to gold retention (%)	122	122

5 The performance properties detailed above describing Example 5
illustrate that this vinyl terminated phenyl substituted polysiloxane in
combination with the silicon hydrocarbon crosslinker is an elastomer with
excellent strength and adhesion properties. Moreover, excellent retention of
these properties is observed on exposure of this material to alcohol based
10 fuels and acids.

Example 6

Example 6 represents a further formulation which demonstrates that
similar properties to the material described in Example 5 can be achieved for
an increased level of the silicon hydrocarbon crosslinker. An encapsulant
15 polymer elastomer was prepared from a vinyl terminated phenyl-substituted
polysiloxane which is 6 mol% substituted with phenyl groups and the silicon
hydrocarbon cross linking agent described above. The material in Example 6
was formulated according to the method described in Example 1, via a two
part process. Compound B shown in Table 23 was blended with 50 wt% of
20 compound A. Compound C shown in Table 23 was blended with the

remaining 50 wt% of compound A. The two parts were mixed, de-aerated, poured into molds suitable for making test pieces and cured at 150°C for 1 hour.

Table 23

Compound	Material	
A	Andsil SF 1721(%)	81.70
B	PT-L (%)	0.30
C	SC-1 (%)	18.00

5

Specimens were cut from each cured piece and measured for physical properties according to ASTM D2240 and ASTM D 412 (using Die D to cut the pieces and a tensile rate of 20inch/minute) with the results shown below.

Hardness (Shore 00)	69
Tensile strength (psi)	126
Elongation (%)	172

- 10 Specimens were also examined for heat resistance according to ASTM D 573 and chemical resistance according to ASTM D 471, part 15.4.2 (using Die D). The results are shown in Table 24.

Table 24

Conditions	Heat 180°C	Fuel C 25°C	Fuel CM 85 25°C	Nitric acid pH 1.0, 85°C
Time (hours)	200	200	200	120
Hardness (Shore 00)	81	70	68	70
Tensile strength retention (%)	211	122	101	132
Elongation retention (%)	46	106	90	87

- 15 The performance properties detailed above describing Example 6 illustrate that this vinyl terminated phenyl substituted polysiloxane in combination with an increased level of the silicon hydrocarbon crosslinker is

an elastomer with excellent strength and adhesion properties. Moreover, excellent retention of these properties is observed on exposure of this material to fuels and acids.

5

Example 7

Example 7 represents six formulations which demonstrate that similar benefits observed for the materials described in Examples 5 and 6 can be achieved with vinyl terminated phenyl substituted polysiloxanes with alternative levels of phenyl substitution and for a range of levels of the silicon

- 10 hydrocarbon crosslinker. Encapsulant polymer elastomers were prepared from varying ratios of a vinyl terminated phenyl-substituted polysiloxane which is 15 mol% substituted phenyl groups and the silicon hydrocarbon cross linking agent described above. Materials in Example 7 were formulated according to the method described in Example 1, via a two part process.
- 15 Compound B shown in Table 25 was blended with 50 wt% of compound A. Compound C shown in Table 25 was blended with the remaining 50 wt% of compound A. The two parts were mixed, de-aerated, poured into molds suitable for making test pieces and cured at 150°C for 1 hour.

Table 25

Compound	Material	Ex 7.1	Ex 7.2	Ex 7.3	Ex 7.3	Ex 7.4	Ex 7.5
A	Nusil PLY-7664 (%)	93.70	86.67	81.70	75.70	69.70	59.70
B	PT-L (%)	0.30	0.30	0.30	0.30	0.30	0.30
C	SC-1 (%)	6.00	13.03	18.00	24.00	30.00	40.00

20

Specimens were cut from each cured piece and measured for physical properties according to ASTM D2240 and ASTM D 412 (using Die D to cut the pieces and a tensile rate of 20inch/minute with the results shown below.

	Ex 7.1	Ex 7.2	Ex 7.3	Ex 7.3	Ex 7.4	Ex 7.5
Hardness (Shore 00)	62.6	70.4	74.6	83.2	-	-
Hardness (Shore A)	-	-	-	-	53	67
Tensile strength (psi)	40	142	197	482	523	672
Elongation (%)	180	173	131	131	95	64
Toughness (in.lbs/in ³)	37	95	99	236	228	227

Specimens were also examined for heat resistance according to ASTM D 573 and chemical resistance according to ASTM D 471, part 15.4.2 (using Die D). The results are shown in Tables 26 to 29.

5

Table 26: Heat for 200 hours at 180°C

	Ex 7.1	Ex 7.2	Ex 7.3	Ex 7.3	Ex 7.4	Ex 7.5
Hardness (Shore 00)	72	82	86	90	-	-
Hardness (Shore A)	-	-	-	-	77	87
Tensile strength retention (%)	216	168	147	98	98	126
Elongation retention (%)	45	38	36	29	27	28

Table 27: Fuel C for 200 hours at 25°C

	Ex 7.1	Ex 7.2	Ex 7.3	Ex 7.3	Ex 7.4	Ex 7.5
Hardness (Shore 00)	60	71	71	82.5	-	-
Hardness (Shore A)	-	-	-	-	77	87
Tensile strength retention (%)	79	87	118	107	-	-
Elongation retention (%)	94	97	109	102	-	-

10

Table 28: Fuel CM 85 for 200 hours at 25°C

	Ex 7.1	Ex 7.2	Ex 7.3	Ex 7.3	Ex 7.4	Ex 7.5
Hardness (Shore 00)	61	71	75	85	-	-
Hardness (Shore A)	-	-	-	-	54	69
Tensile strength retention (%)	127	94	125	106	103	122
Elongation retention (%)	94	90	105	97	101	120

Table 29: Nitric acid for 120 hours at pH 1.0, 85°C

	Ex 7.1	Ex 7.2	Ex 7.3	Ex 7.3	Ex 7.4	Ex 7.5
Hardness (Shore 00)	62	73	77	85	-	-
Hardness (Shore A)	-	-	-	-	59	77
Tensile strength retention (%)	189	125	120	105	117	124
Elongation retention (%)	110	88	89	83	86	84

- The performance properties detailed above describing Example 7
- 5 illustrate that this vinyl terminated phenyl substituted polysiloxane in combination with the silicon hydrocarbon crosslinker can be a soft gel material with excellent strength and toughness. Moreover, good retention of these properties is observed on exposing these materials to fuels and acids. The heat resistance of this material is equal to or better than a vinyl
- 10 terminated phenyl substituted polysiloxane in combination with a cross linking agent that is a linear hydrosiloxane with dimethyl substitution (see Comparative Example 2). Furthermore, at increased levels of the silicon hydrocarbon crosslinker, more rigid materials are generated which demonstrate greatly increased levels of toughness while remaining flexible.
- 15 Moreover, good retention of these properties is observed on exposing these materials to acids and alcohol based fuels.

Comparative Example 2

- A further encapsulant polymer gel was prepared from a vinyl
- 20 terminated phenyl-substituted polysiloxane which is 15 mol% substituted phenyl groups and a cross linking agent that is a linear hydrosiloxane with dimethyl substitution. The material in Comparative Example 2 was formulated according to the method described in Example 1, via a two part process. Compound B shown in Table 30 was blended with 50 wt% of compound A.
- 25 Compound C shown in Table 30 was blended with the remaining 50 wt% of

compound A. The two parts were mixed, de-aerated, poured into molds suitable for making test pieces and cured at 150°C for 1 hour.

Table 30

Compound	Material	
A	Nusil PLY-7664 (%)	81.70
B	PT-L (%)	0.30
C	Masil XL-1 (%)	18.00

- 5 Specimens were cut from each cured piece and measured for physical properties according to ASTM D2240 and ASTM D 412 (using Die D to cut the pieces and a tensile rate of 20inch/minute) with the results shown below.

Hardness (Shore 00)	61.8
Tensile strength (psi)	61.42
Elongation (%)	251.2
Toughness (in.lbs/in ³)	63.21

- Specimens were also examined for heat resistance according to ASTM D 573 and chemical resistance according to ASTM D 471, part 15.4.2 (using Die D). The results are shown in Table 31.
- 10

Table 31: Heat and Chemical resistance

Conditions Time (hours)	Heat 180°C 200	Fuel C 25°C 200	Fuel CM 85 25°C 200	Nitric acid pH 1.0, 85°C 120
Hardness (Shore 00)	78	69	63	71
Tensile strength retention (%)	299	117	105	206
Elongation retention (%)	32	74	81	66

- 15 The performance properties detailed above describing Comparative Example 2 illustrate that this vinyl terminated phenyl substituted polysiloxane in combination with a cross linking agent that is a linear hydrosiloxane with

dimethyl substitution is a soft gel material with inferior strength and toughness compared with Examples 5 to 7. Moreover these properties are observed to deteriorate on exposure of this material to both fuels and acids, indicating polymer degradation.

5

Example 8

Example 8 represents two formulations in which a blend of a vinyl terminated fluorine containing polysiloxane and a vinyl terminated phenyl substituted polysiloxane is used in conjunction with the silicon hydrocarbon crosslinker. Encapsulant polymer gels were prepared from blends of a vinyl terminated fluorine containing polysiloxane, which is 50 mol% substituted with 3,3,3-trifluoropropyl groups, and a vinyl terminated phenyl-substituted polysiloxane, which is 15 mol% substituted phenyl groups, in different ratios, and the silicon hydrocarbon cross linking agent described above. Materials in Example 8 were formulated according to the method described in Example 1, via a two part process. Compound B shown in Table 32 was blended with 50 wt% each of compounds A. Compound C shown in Table 32 was blended with the remaining 50 wt% each of compounds A. The two parts were mixed, de-aerated, poured into molds suitable for making test pieces and cured at 150°C for 1 hour.

Table 32

Compound	Material	Ex 8.1	Ex 8.2
A	Nusil PLY-7801 (%)	65.36	73.53
	Nusil PLY-7664 (%)	16.34	8.17
B	PT-L (%)	0.30	0.30
C	SC-1 (%)	18.00	18.00

- Specimens were cut from each cured piece and measured for physical properties according to ASTM D2240 and ASTM D 412 (using Die D to cut the pieces and a tensile rate of 20inch/minute) with the results shown below.

	Ex 8.1	Ex 8.2
Hardness (Shore 00)	71	64
Tensile strength (psi)	69	64
Elongation (%)	111	185
Toughness (in.lbs/in ³)	46	49

Specimens were also examined for heat resistance according to ASTM D 573, 180°C for 200 hours, with the results shown below.

	Ex 8.1	Ex 8.2
Hardness (Shore 00)	81	75
Tensile strength retention (%)	120	132
Elongation retention (%)	45	41
Toughness retention (%)	81	49

- 10 The performance properties detailed above describing Example 8 illustrate that blends of vinyl terminated fluorine containing polysiloxane and vinyl terminated phenyl substituted polysiloxane in combination with the silicon hydrocarbon crosslinker are gel materials with good strength, flexibility and heat resistance.

Comparative Example 3

A further encapsulant polymer gel was prepared from a blend of a vinyl terminated fluorine containing polysiloxane which is 50 mol% substituted with 3,3,3-trifluoropropyl groups with a vinyl terminated phenyl-substituted polysiloxane which is 15 mol% substituted with phenyl groups and a cross linking agent that is a linear hydrosiloxane with either dimethyl substitution or 3,3,3-trifluoropropyl substitution. Materials in Comparative Example 3 were formulated according to the method described in Example 1, via a two part process. Compounds B shown in Table 33 was blended with 50 wt% each of compounds A. Compound C shown in Table 33 was blended with the remaining 50 wt% each of compounds A. The two parts were mixed, de-aerated, poured into molds suitable for making test pieces and cured at 150°C for 1 hour.

Table 33

Compound	Material	CEx 3.1	CEx 3.2
A	Nusil PLY-7801 (%)	65.36	65.36
	Nusil PLY-7664 (%)	16.34	16.34
B	PT-L (%)	0.30	0.30
C	Masil XL-1 (%)	18.00	-
	SMP 9951-22 (%)	-	18.00

Specimens were cut from each cured piece and measured for physical properties according to ASTM D2240 and ASTM D 412 (using Die D to cut the pieces and a tensile rate of 20inch/minute with the results shown below.

	CEx 3.1	CEx 3.2
Hardness (Shore 00)	51.5	33
Tensile strength (psi)	26.4	16.2
Elongation (%)	134.4	342.4
Toughness (in.lbs/in ³)	14	27

Specimens were also examined for heat resistance according to ASTM D 573, 180°C for 200 hours, with the results shown below.

	CEx 3.1	CEx 3.2
Hardness (Shore 00)	84	54.5
Tensile strength retention (%)	256	121
Elongation retention (%)	14	41
Toughness retention (%)	25	17

- 5 The performance properties detailed above describing Comparative Example 3 illustrate that blends of vinyl terminated fluorine containing polysiloxane and vinyl terminated phenyl substituted polysiloxane in combination with cross linking agents that are linear hydrosiloxanes with either dimethyl or 3,3,3-trifluoropropyl substitution are soft gel materials with inferior strength,
- 10 toughness and heat resistance compared with Example 8.